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AN INFORMATION TECHNOLOGY VIEW OF MANUFACTURING AUTOMATION - PRODUCT LIFE-CYCLE MANAGEMENT

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Abstract: Different approaches of product life-cycle management will be demonstrated to show that unlike several engineering paradigms it is easy to understand, however difficult to implement and to follow. This can be accepted as a common philosophy of product development and production. At the same time product life-cycle management is a software framework, or a kind of guideline to approach digital manufacturing, which is the highest level of recently known and applied ways of manufacturing automation. The paper will show some components of manufacturing automation and their relation to the life-cycle view.

Keywords: Digital manufacturing, Life-cycle, Manufacturing, Automation, Design

1. Introduction

Product Life-Cycle Management (PLM or PLCM or sometimes LCM) is a relatively young engineering paradigm. One of the best fitting definitions of PLM is the following: PLM is an information management system that can integrate data, processes, business systems and, ultimately, people in an extended enterprise. PLM software allows you to manage this information throughout the entire lifecycle of a product efficiently and cost-effectively, from ideation, design and manufacture, through service and disposal. The goals of this study are: to give some ideas on the several possibilities to connect product and production development in the most recent trends of manufacturing automation, namely in digital manufacturing, and to show some possible solutions, how an information technology framework can be applied based on product life-cycle management. This is not a survey paper, just it will give a slightly different view from the usually applied, when taking into account different factors effecting PLM. It is easy to understand from one side, as it is almost common sense, and extremely complicated and hard to realize from the other side.

The two sides in the above context are the following.

1.1. A simple minded human view

First of all how to understand ‘product’ and ‘life-cycle’ have to be clarified.

What is a product? First a simple definition is given to easily understand ‘product’. Everything, what is done or obtained for being used by humans can be taken into account as a product. For example a car is a product, a software module, or a computer program to solve a problem is a product, or a factory is product, or even a piece of wood used to make a chair, or to burn in the oven is a product.

Now, if it is true that (almost) everything can be a product, it is easy to imagine that all products have to be taken care, or have to be followed, supervised, etc. with one recent word; all products have to be managed through their total life-cycle [1], [2], [3].

What is life-cycle? It is the total life-span of the product from the conception of its idea (‘I will make a car’, ‘I need a piece of wood to my oven’, etc.) until the End-Of-Life (EOL) of it, through all steps of its existence. In the case of a piece of wood for heating it means the following: ‘I need the wood, I find it (or break it, or cut it), I take it home, cut it, if necessary, burn it and then as the last step I will reuse or recycle or simply bury the ashes.’

If the product is a car, the life-cycle is more complicated and longer to describe: from the idea, trough design, implementation (producing and assembling all parts), then sell it, use it until it is getting useless or broken in accidents until burial or reuse or recycling. But it is not all: service, sales, advertisement, ID papers, and everything connected to that car belong to the life-cycle; and are managed by PLM [4].

1.2. The view of a computer expert (*informatics guru*)

This is the other view i.e. the view of a person, a programmer, a system manager, who has to manage all data, information, and knowledge connected or related, i.e. to keep in hand during the total life-cycle of the corresponding objects, which are called products in the recent context. Just an example: it is hard to explain and to understand the following issue: if someone designed a car digitally and gave it over to production. That is all files are in the hands of the maters of manufacturing the work is not yet done, but someone has to take care of sales, service, etc. All steps are connected, using the same information added, generated. And moreover it is not only technical and financial information but for example now even the ‘greens’ may influence a lot of things with statements and orders, like: ‘do not leave the crashed car on the street, take care of the environment!’, and ‘if you just leave on the fields the used battery’, etc. Several other issues influence the life cycle of any product. Even Human Resource Management (HRM) is a part of the information to be managed.

From the Information Technology and Communication (ITC) point of view: distributed data-and knowledge bases, huge files, all with different sizes, on different computers and in huge, separate memories, with unique and redundant information call for management. The information contains text, numerical, logical and graphical information as well.

The problem of getting the appropriate information from the right place in the right time and communicating, and storing, what is assigned for these actions may be extremely complex, and need plenty of energies and time [5].

Partially the above problems and emerging new points of view resulted in the fact, *service engineering and maintenance engineering* became new, independent paradigms of Manufacturing Automation (MA) and of PLCM, and new types of relationships emerged and are used worldwide.

1.3. General issues of ITC supported production

At the same time modern production is pushed to produce faster, cheaper, in better quality. The reasons can be found in the worldwide globalization and competition, in increasing customer demands, and in the broader and broader possibilities of the production. [6], [7]. The mass production, the one-of-a kind and the serial production still exist and are decisive, however a new wave is the combination of mass- and one of-a-kind- production, what is getting momentum recently. The so called 'one-of- a-kind mass production', what sounds like a contradiction is typical in car manufacturing of BMW or Mercedes or Porsche, etc. where every car is unique, as the customer requests. The cars may be different only in color, or in type and output of the engine, or in material of the seats, etc.; still the same mass-production lines are used, with a little more sophisticated software support.

It is interesting to compare this idea with the early T-Model of Henry Ford in the very beginning of the 20th century, when Ford could say and do: 'I will tell them, what car they will use' and no other cars were produced by the Ford Motor Company for years. Times, requirements, demands and possibilities changed a lot, mostly due to computer/information technology, and due to organizational changes.

Not only the production itself is changed, but the presence and influence of Small and Medium Enterprises (SMEs) is getting more and more important. And SMEs are not satisfied by the traditional hierarchical structures of enterprises, as they cannot find their appropriate places, and want to keep certain independence. As a consequence several factories are changing their work-and organization structures to the so called heterarchical ones with new types of management and control. Heterarchical organization has a basic meaning of equality of partners in most (or all) work structures and decision making. The new types of enterprises with well-established heterarchy are called extended or virtual enterprises; however these are not exactly the same.

One more general remark: the strong separation of designers, manufacturers, sales people and management within factories are disappearing, and integration comes into effect meaning that all important decisions are done together, i.e. engineering and finance and even HRM are working together, using the same data base (knowledge base, repository, ontology, etc.). Naturally, if different people, working probably in different countries, use the same computer programs, there are several safety and security and trust problems to be solved, partially with the rather hard definition and application of access rights.

Before of going further short rest is necessary. The authors of this paper used to teach information technology and engineering applications through several years, and created a simple, (maybe simple-minded) axiom at least thirty years ago, to be able to better explain Computer-Aided Design and -Manufacturing (CAD), (CAM) and related paradigms. It can be called the 'Axiom of all computer applications'

1.4. Axiom of all computer applications:

If there exist error-free (perfect) input data & perfect programs, the results of the program runs will be error free as well.

This axiom makes it worthwhile to deal with complex, huge computer and program-systems. If there are more than 2-3-4 programs in a system, which use results of other program-runs as input, and which are producing output that will be the input of other programs, some assistance is needed to understand what is actually happening.

It is a new view and experience that PLM can be a good frame and tool to control (manage), to understand and to follow what is going on in the informatics side.

2. PLM and its basic components (steps, phases)

The following list and some similar lists in the text contain the commonly used steps (or elements or phases) of PLM, however there are not yet fixed standards, just practical solutions. Generally for a simple product fewer steps are needed, and for complex products more steps are necessary. For example for a simple 'product design' one step may be enough, or 'design' may be included into 'analysis' or into 'implementation'.

For complex products 3-4 or more (sometimes much more) 'design steps' are required, as preliminary design, general design, detailed design, fine tuning, etc. In the conclusion of this paper a more complete list will be given.

PLM means more than some design steps, it is everything from idea through birth (requirements and analysis and conception and understanding) and design, implementation, integration, manufacturing, assembly, operation until death and dismissal/burial (reuse, recycling) including sales, service, advertisement, etc.

The picture is more colorful as products may be rather different by definition and by character. Just for example the following expressions can be used to qualify or identify products:

Real, Virtual, Extended, Tangible, Intangible; Simple, Complex.

The production and the production systems should have the same categories as those of the products. Recently the most commonly used definitions are the '*virtual'* or '*extended'* factory. Fifty years ago there were only *real products*, which were *simple or complex*. There are *tangible and intangible* products as well.

It can be mentioned with restricted seriousness, that there are not yet intangible factories, however 'the fractal company' and even the chaotic company are present in the literature [8].

All system development techniques and technologies (traditional, or object oriented) are working to accomplish PLM. Thus all commonly known system tools as System Analysis and Design Technique (SADT), Object Modeling Technique (OMT), Object Oriented Software Engineering (OOSE) or Rational Unified Process (RUP) and United Modeling Tool (UML) are leading to PLM in a direct way [9].

2.1. What is PLM? Why to use PLM? An easy to understand approach

The Introduction gave a good definition of PLM, now the following pages show different views of PLM through some examples, as:

- PLM, as one of the four-legs of a digital production model;
- A Computer Integrated Manufacturing (CIM) model from 1970;
- A recent CIM model;
- Four books edited by the author, the so called ‘melon model’ is defined in [7], [10];
- Object Oriented System Engineering (Jacobson), [11];
- Ecology-footstep model of Michelini and Kovács [9], [12],[13];
- An up-to date graphically and professionally nice definition.

Seven, partly different examples are just demonstrating something, however there are several further examples, which all would be already a proof that PLM (PLCM) can be used as a framework or as a frame for keeping programs of the digital production under control. Similar examples could be: test, diagnoses, error detection and correction, run-time measurements, different technologies (as sheet forming), etc.

PLM is one of the four legs of digital production

The four legs should contain everything necessary to have digital, networked, virtual, highly effective factories, enterprises. A possible set of 4 legs is the following, (see *Fig. 1*):

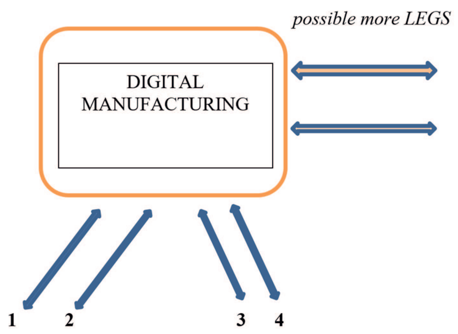

Fig. 1. Four (or more or less) legs of digital production

1. Digitally controlled machines, machine-tools (with controllers, machine tools with computer control, etc.) and interfaces to computers, controllers and to networks;
2. Computers and networks and appropriate programs;
3. Design, Part level: Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM) and Computer Numerical Control (CNC), etc;
   Design, System level: Object Oriented Software Engineering (OOSE), Object Modeling Technique (OMT) and System Analysis and Design Technique (SADT), etc.;
4. A Philosophy, i.e. a common way of understanding and using them, to keep all together: it is done (realized) by the 'Product Life-Cycle Management'.

It is clear that this model may consist of more than 4 legs, or less, than 4 legs, and these legs may differ from the 4 defined here. For example the 2 parts of No. 3 (3a part level and 3b system level) could be taken separately as well (see *Fig. 1*), however only this set of legs is acceptable, which together represent everything that may be necessary.

An early CIM model, 1970

When CIM was only a dream some people in SZTAKI understood that there were consecutive steps of the design and production, which were built upon each other, and all depended on the previous ones. It was the first time we spoke about integration.

There is a simple, logical, but sometimes for some people hard to accept consideration: the information content of the whole system may never decrease. An arrow points on the direction and existence of PLM, pointing down.

System development and manufacturing have the following main phases of PLM, see *Fig. 2* for some of them. The others are missing or hidden. The figure shows that every program may run after a previous one and they get data from the previously used program and from the external world as well, see CAD, CAM, CAQ (Computer Aided Quality) for example, or RS, AN and D:

- *Logical design*: Requirements Specification (RS), ANalysis (AN), Design (D);
- *Construction design*: Design, Implementation, Integration;
- *Manufacturing, Assembly:* Test, diagnosis, Maintenance.

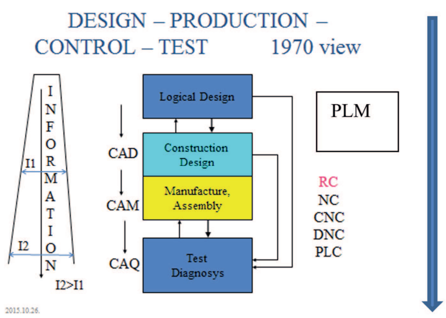

Fig. 2. PLM in an old, still correct CIM view, 1970

Fig. 3 shows the difference between our 1970 model and a recent PLM model. In the 1970 model the data processing and flow were definite, always the same and there were only some loops for corrections, which are not represented in the figure.

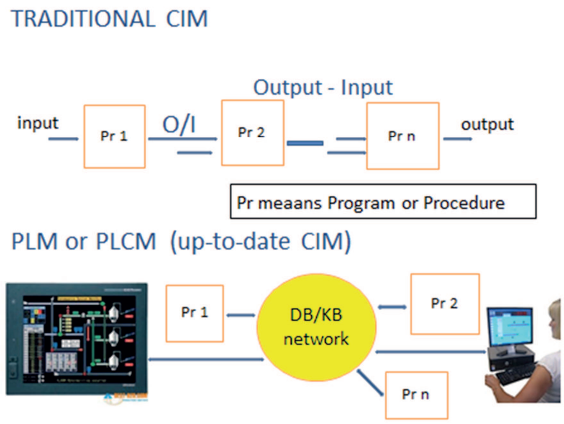

Fig. 3. Two PLM software views (traditional & up-to-date)

Some books, which contribute a lot to understand, to explain and to use PLM

Product Life-Cycle Management has important role in several books and conference proceedings can be seen in the References section. Four of these books will be mentioned under [7], [8], [9], [10]. Two of them are present in only with the book title, the other two with a paper and the book title. They were published in 1999, 2003, 2006 and 2013 respectively.

The first one is the collection of the best papers of 3-4 conferences and workshops held earlier, with strong explanations of the relationships between the different topics, however PLM has already important role in cooperative knowledge solving used for engineering tasks.

The other three books contain the best papers of the last three IFIP PROLAMAT (Programming Languages for Machine Tools) conferences. The name, PROLAMAT is unchanged; however the content is always up-to- date. These conferences were held in Budapest 2001 [8], [13] Shanghai 2006 [9] and Dresden 2013 [7], [10]. The Dresden meeting presented a strong and high level car-manufacturing participation, often dealing with PLM.

This fact shows and proves that complex tasks can be solved, only if appropriate frames and philosophies are used, and that PLM is able to serve as a philosophy for the domain of car making, i.e. for manufacturing automation.

The 'melon model' (*Fig. 4*) is the work of Arthur Baskin and George Kovács, [7] and [10] and it explains all internal and external effects on knowledge management. PLM belongs to the central part of the figure, the rest seems to be complicated, but as a matter of fact it is logical and understandable.

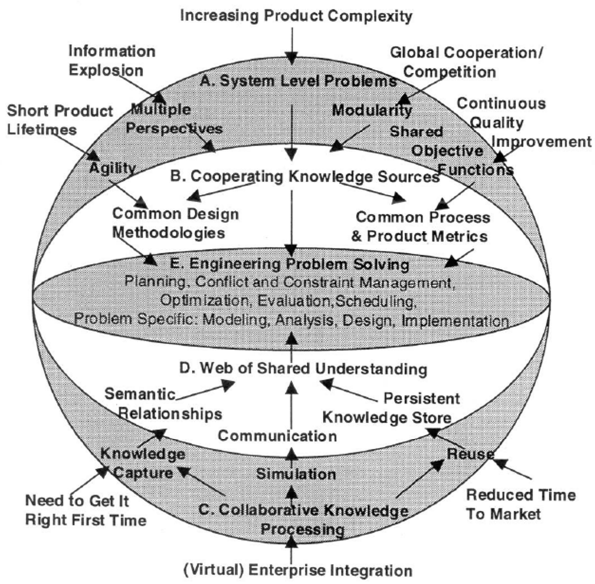

Fig. 4. The external forces driving the development, it is the melon model

There are internal and external forces of Collaborative Knowledge Processing (CKP) for Engineering Problem Solving (EPS) and the most important ones are in the figure above - representing only the main directions of the effects. Some important relationships are explained by the figure, too.

Use case model, Jacobson, 1992

Just to speak about a design methodology as well [11] the Object Oriented System Engineering (OOSE) is chosen. OOSE is a design philosophy and methodology, which has a basic unit: the *use-case* (see *Fig. 5*).

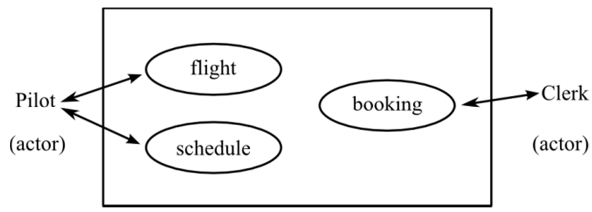

Fig. 5. A use-case model

It means a kind of an action or a happening plus a dialogue, which starts and ends in well-defined points. (Use-case design was taken over and used by several other design systems as well). For example there are two actors in this simple model in *Fig. 5*. A pilot taking care of the flying and of the schedule and a clerk is giving information on the schedule and selling tickets. However in this little example the two actors may be one person [11].

Fig. 6 shows the PLM character of the procedure and the relationships built up to explain and to understand the real advantages of Object Oriented (OO) design.

There are some models generated during development from the use-cases and their OO description Domain Object Model (DOO) of all use-cases. The point is that the same objects are alive during the whole procedure and only the changes (transformations) have to be taken care of. See *Fig. 6* and the text explanation below it.

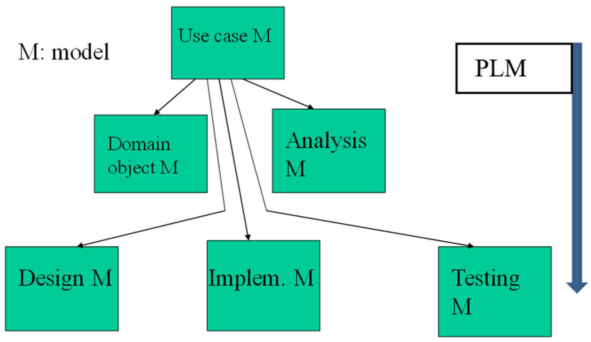

Fig. 6. PLM and use-case model relationships in OOSE

The following lines explain how to read *Fig. 6,* which has 6 models and 5 statements connecting some of them.

The use-case model

- Is expressed in terms of the Domain Object Model;
- Is structured by the Analysis Model;
- Is realized by the Design Model;
- Is implemented by the Implementation Model;
- Is tested in the Test Model.

Maintenance Model (MM) was not yet taken into account, however 20 years ago, it was added to the OOSE procedure and model.

PLM (LCM)-Ecology-evaluation relationships

A completely different goal gave inspiration to deal with *environment - costs - ecology* relationships, as the goal was to take environment into consideration when the value chain was calculated step by step during product design and production, etc. This way it was clear that this model carried the PLM features [12], [14].

Fig. 7 primarily deals with PLM and ecology, footstep, sustainability problems; however the importance of reuse and recycling is underlined, too. This model shows how PLM is related to several other things, even to primary and secondary effects of sustainability, i.e. losses generated in order to be sustainable [15], [16].

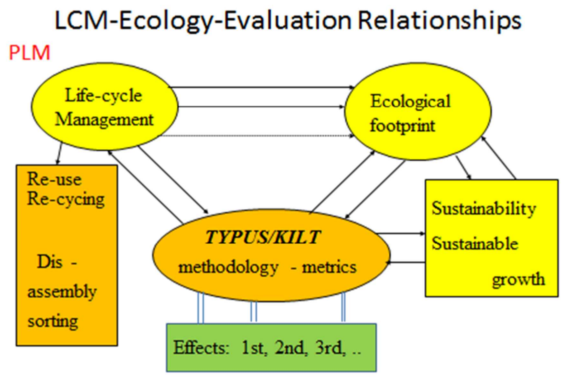

Fig. 7. PLCM-some ecology-evaluation relationships

Finally, as a last PLM example, (see *Fig. 8*) just to mention without going into details, a correct and nice view, where most important components are presented as:

- *Product is the core*, containing data, technology, methods, tools, and their programming support as CAD, CAM, Computer Aided Engineering (CAE), Computer Aided Process Planning (CAPP), in general Computer Aided Solutions, programs (CAxx), Product Data Management (PDM), etc.;
- *The upmost layer is the Management* with services, marketing, general design, engineering, procurement, manufacturing, etc.;
- *Between product and management there is the lifecycle* with conceive, develop, realize and use, however it should not have this content [17].

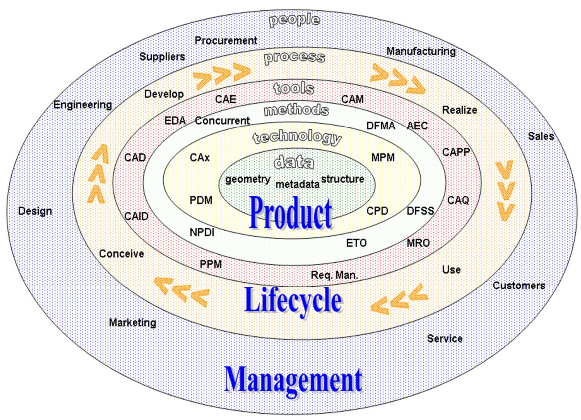

Fig. 8. A recent view of PLM

3. Conclusions

PLM (PLCM) is a general framework, a set of software solutions, guidelines, etc. to approach to digital manufacturing, i.e. digital, networked, extended, virtual enterprises of several units.

If PLM is explained to a normally educated non-technical person, it may sound the following way:

Product Life-cycle management is the way as parents take care of their children, and children take care of the parents in their last years: from the idea, through conception, through birth until the burial. This caretaking is well designed for every time and occasion.

If an explanation is presented to engineering or information technology students, or to any technical people, it should be more precise. Instead of a general definition an arbitrary example is often used: This time car making is the example.

PLM is a procedure in which if you decide to make a new car, you have to design and implement not only the car itself, but you have to design service, maintenance, advertisement, sales, etc. and even what to do in case of an accident, or what to do with the used tires, or what to do with the dangerous materials, when the car finishes its life, and several other issues.

It is not easy, as there are too many, different type of things to be managed properly, knowing all possible requests that the software manager has to fulfill.

Just to remember some arbitrarily defined and selected main steps of the PLM of an industrial product will be summarized. Arbitrarily means that there are several other possibilities to define and to use. The choice is intentionally similar to the 1970 model:

- *Logical design*: Idea, Understanding it, Requirements specification, Analysis, Corrections (Feed-back is present at all steps generally);
- *Design:* Preliminary, Sketch, Detailed, Parts, Assembly, and Disassembly Planning;
- *Construction design*: Design, Implementation, Integration, Preparation for Assembly;
- *Manufacturing, assembly*: Part Production, Mounting, assembly;
- *Test, diagnosis, follow up*: Implementation, Testing, Integration and Maintenance, Service, Marketing, Sales, Advertising, Human Resource Management, Bill of Materials, etc.;
- *Management of EOL* (end of life products): Dismounting: Sorting, Qualification, Reuse, Recycling, Shredder.

It is easy to understand, hard to manage in real, interconnected, networked design offices, workshops and factories of any kind, even with appropriate software support, however large organizations need and use similar systems to keep in hand all processes and products in an economic, transparent way. For example properly selected and integrated Systems Applications and Products (SAP) subsystems can be taken and are used as (partial) solutions for PLM.

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